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The value of information sharing in a multi-product, multi-level supply chain: Impact of product substitution, demand correlation, and partial information sharing

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ABSTRACT

The literature on the value of information sharing within a supply chain is extensive. The bulk of the literature has focused on two-level supply chains that supply a single product. However, modern supply chains often have more than two levels and supply many products. Because many of these products are variants of the same base product, they tend to be substitutes and their demands correlated. Further, achieving supply-chain-wide information sharing in a multi-level supply chain is challenging because different firms may have different levels of incentives to share information. We analyze the value of information sharing using a comprehensive supply chain that has multiple levels, may have different degrees of information sharing, and supplies multiple products that may have different levels of substitutability and whose demands could be correlated to different degrees. Our analysis shows that substitution among the different products reduces the value of information sharing for all firms in the supply chain. The reduction is higher (i) for firms that are more upstream, (ii) when the degree of substitution is higher, (iii) when the number of substitutable products is higher, (iv) when the demands of products are more correlated, and (v) when the degree of information sharing is higher. Our results suggest that firms, especially those that are upstream in the supply chain, may face a significant risk of over-estimating the value of information sharing if they ignore substitution, demand correlation, and partial information sharing effects.

1. Introduction

Information sharing is viewed as one of the key elements for successful supply chain management and coordination. Information sharing can reduce the risk brought by asymmetric and incomplete information, cut down lead time, mitigate bullwhip effect, and reduce total cost and increase total supply chain profit [19,20]. Information sharing enables suppliers to respond to consumer demand more quickly by appropriately scheduling the replenishment of the inventory. Continuous Replenishment Program (CRP) and Vendor Managed Inventory (VMI) are efforts in this direction. The savings in inventory holding and shortage costs to Campbell Soup Company and its retailers because of CRP have been documented in [8,21]. Information sharing often improves the accuracy of demand forecasts, which enables a better price structure, improved production scheduling, and better management of consumer demand. Schemes such as Collaborative Forecasting and Replenishment (CFAR) facilitate sharing of both long-term and short-term demand forecasts between manufacturers and retailers.

The value of information sharing within a supply chain has been analyzed extensively in prior research. Bulk of the literature has investigated the case in which the supply chain manufactures and distributes a single product to customers. However, the ability to satisfy heterogeneous customer preferences by providing more product variety is a critical success factor in retailing [18], and modern supply chains often manufacture and distribute multiple varieties of a product [10]. Recognizing this, Ganesh et al. [11] studied the impact of demand substitution on the value of information sharing when a supply chain distributes multiple varieties of a product. That is, when a variety that a customer is looking for is unavailable, the customer may buy another variety of the same product. They showed that demand substitution diminishes the value of information sharing.

Existing studies on value of supply chain information sharing including Ganesh et al. [11] have used a two-level supply chain consisting of a manufacturer and a retailer. However, depending on the complexity of the product and other factors such as the distance between locations of manufacturers and end consumers, the number of levels in the supply chain can vary. Existing studies do not offer much insight into relative incentives of firms at various levels within a supply chain to share information with their trading partners.

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We extend Ganesh et al. [11] in the following directions. First, we consider an N-level supply chain whereas Ganesh et al. [11] considered a two level supply chain. This extension has allowed us to not only generalize the findings of Ganesh et al. [11] for a more general supply chain but also examine how the impact of product substitution on the value of information sharing varies across different levels of a supply chain. Second, we consider different degrees of information sharing, which cannot be analyzed in a two-level supply chain. In a two-level supply chain, since there are only two firms, we have only two cases: the two firms share information or they do not. In an N-level supply chain, various information sharing possibilities arise, depending on which firms have an incentive to share their information with their upstream partners. We consider two broad types of information sharing: upstream and downstream. In downstream (upstream) information sharing, the firms that are closest to the customer (raw material supplier) share their demand information with their suppliers, but firms that are near the raw material supplier (customer) of the supply chain do not share their demand information. Within each type, we examine different degrees or extents of information sharing. This analysis provides insights into the value of partial information sharing within supply chains.

Our analysis shows that substitution reduces the value of information sharing for all firms in the supply chain. This result generalizes the key result of Ganesh et al. [11] to the N-level supply chain regarding the effect of demand substitution on the value of information sharing. Additionally, we find the following new results. The reduction in the value of information sharing because of substitution is higher (i) if the degree of substitution is more, (ii) if the number of products is more, (iii) if demands of products are less correlated, (iv) for firms that are more upstream and (v) if the degree of information sharing is higher. Our results suggest that firms, especially those that are upstream in the supply chain, may face a significant risk of over-estimating the value of information sharing if they ignore substitution, demand correlation, and partial information sharing effects.

2. Literature review

There is a significant body of literature in supply chain information sharing. Most papers in this stream of research analyze a two-level supply chain with a single manufacturer and a single retailer using a variety of demand models with different sets of assumptions (e.g., [5,7,12–14,28,38]). Our work is closely related to the literature that uses AR(1) demand model to study value of information sharing. Lee et al. [22] showed that the benefit of demand information sharing can be significant when either lead time or the serial correlation coefficient is large. Raghunathan [33] showed that the results derived by Lee et al. [22] overestimate the benefit of demand information sharing if the manufacturer uses the entire order history to do its forecast. A few papers have investigated models with a single manufacturer and multiple retailers (e.g. [1,2,6,42]). Raghunathan [34] and Raghunathan and Yeh [35] examined the value of demand information sharing using an N retailer version of the model in Lee et al. [22]. Huang and Iravani [16] analyzed how information sharing by one of two retailers affects the value of information sharing. Leng and Parlar [23] studied the information sharing in a three-level serial supply chain and analyzed sharing of the benefits from information sharing using the Shapley value concept.

Another stream of research has investigated how information sharing affects pricing decisions within a supply chain. These papers do not investigate inventory-related issues. Li [24] analyzed a model that included a manufacturer and several competing retailers and showed that retailers will not voluntarily share information. Zhang [41] considered a model in which each retailer sells a different product developed from the same base product supplied by the manufacturer and allows these products to be either substitutes or complements. Li and Zhang [25] analyzed the impact of three information sharing scenarios between retailers and the manufacturer, with varying degrees of confidentiality. Mishra et al. [29] showed that both the manufacturer and the retailer have incentives to share distorted information.

There is a vast literature on the effects of substitution among products. For example, researchers have studied the problem of economic order quantity and stocking level when a firm sells substitutable products [17,27,31,40]. Because the exact solution for the optimal inventory level is unavailable even for a simple two-product model with substitution, Rajaram and Tang [36] developed heuristics to determine approximate inventory level. The literature on product substitution can be classified into two main categories. In the first category, firms may choose to fill demand for one product using the inventory of another, perhaps, that of a higher quality product, to avoid losing the sale. Research on such "one-way substitutability" includes Bassok et al. [3], Bitran and Dasu [4], Rao et al. [37], and Honhon, Gaur, and Seshadri [15]. In the second, substitution decisions are not directed by firms; rather, they are made by customers. Our paper models substitution of the second type. Mahajan and Ryzin [26] and Smith and Aggrawal [39] developed models that capture dynamic customer arrivals within a substitutable products context. Dynamic customer arrivals capture the more realistic scenario of different products going out of stock at different time periods. Parlar [30], Pasternack and Drezner [32], and Drezner et al. [9] investigated the impact of substitution in a competitive setting in which consumers may go to another retailer when their preferred retailer is out of stock. As stated in the Introduction section, Ganesh et al. [11] considered the case in which a two-level supply chain distributes multiple substitutable products. Our work extends this by considering an N-stage supply chain with different types of information sharing. This allows us to derive insights about the impact of substitution on firms that are at different levels within a supply chain and about the impact of substitution under partial information sharing.

3. Modeling framework

We consider an N-Stage supply chain, which distributes P products, as shown in Fig. 1.

Following earlier studies on supply chain information sharing [22,33,34], we assume that the demand faced by firm 1 for product j (or equivalently, the consumer demand for product j), $D(1)_j$, follows an order one auto-regressive, AR(1), process. Thus, the consumer demand for product j during period t is given by:

$$D(1)_{j,t} = d + \rho D(1)_{j,t-1} + \xi_{j,t} \tag{3.1}$$

where $d>0$, $-1<\rho<1$, and $j\in\{1,2,3,\ldots,P\}$. For a given t, $\xi_{j,t}$ follows a normal distribution with mean zero and variance σ^2, and the correlation coefficient between $\xi_{j,t}$ and $\xi_{i,t}$, $i\neq j$, is ρ_r, $-1/P-1<\rho_r<1$. Both σ^2 and ρ_r are independent of t and j. The condition $-1/P-1\le\rho_r\le1$ guarantees that the covariance matrix of $\xi_{j,t}$ is positive semi-definite. For a given i, $\xi_{j,t}$ are *i.i.d.* We assume further that σ is significantly smaller than d, so that the probability of a negative demand for any product during any period is negligible. All firms in the supply chain use an AR(1) model for forecasting their demands.

We consider a periodic review system in which, at the end of every period, each firm in the supply chain reviews its inventory level and places an order with its immediate upstream firm to

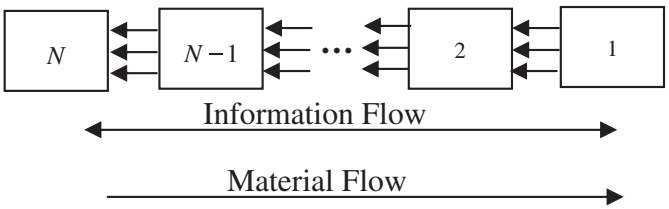

Fig. 1. N-stage supply chain model.